REPORT RESUMES

ED 020 901 SE 004 883

INDUSTRIAL RADIOGRAPHY INSTRUCTOR'S GUIDE.
OFFICE OF EDUCATION (DHEW), WASHINGTON, D.C.
REPORT NUMBER OE-84034 PUB DATE MAR 68
ATOMIC ENERGY COMMISSION, OAK RIDGE, TENN.
EDRS PRICE MF-$0.50 HC-NOT AVAILABLE FROM EDRS. 62P.

DESCRIPTORS- *INSTRUCTIONAL MATERIALS, *NUCLEAR PHYSICS, *TEACHING GUIDES, ADULT EDUCATION, CHEMISTRY, EDUCATIONAL PROGRAMS, LABORATORY MANUALS, PHYSICS, TECHNOLOGY, VOCATIONAL EDUCATION, UNITED STATES ATOMIC ENERGY COMMISSION, UNITED STATES OFFICE OF EDUCATION,

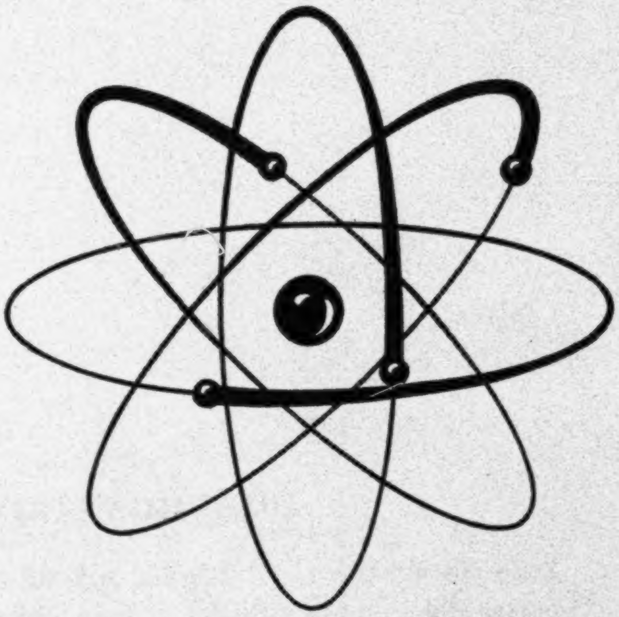
THIS LABORATORY GUIDE WAS DEVELOPED FOR AN 80-HOUR COURSE IN INDUSTRIAL RADIOGRAPHY FOR HIGH SCHOOL GRADUATES TRAINING TO BECOME BEGINNING RADIOGRAPHERS. IT IS USED IN CONJUNCTION WITH TWO OTHER VOLUMES--(1) INDUSTRIAL RADIOGRAPHY INSTRUCTOR'S GUIDE, AND (2) INUDSTRIAL RADIOGRAPHY MANUAL. THE PROGRAM WAS DEVELOPED BY A COMMITTEE OF REPRESENTATIVES FROM INDUSTRY, FROM THE U. S. OFFICE OF EDUCATION, AND THE ATOMIC ENERGY COMMISSION. THE EFFORT AROSE OUT OF A CONCERN FOR (1) REDUCING OVEREXPOSURE HAZARDS TO RADIOGRAPHERS, AND (2) INCREASING THE AVAILABILITY OF MANPOWER IN THIS FIELD. THE BOOK IS DIVIDED INTO TWO PARTS--(1) STUDENT GUIDE, CONSISTING OF QUESTIONS AND EXERCISES BASED ON THE RADIOGRAPHY MANUAL, AND (2) LABORATORY EXERCISES, CONSISTING OF 15 EXPERIMENTS, A LABORATORY TEST, A SOURCE UTILIZATION RECORD, AND A TRAINING PROGRAM SCHEDULE. THE LABORATORY EXERCISES INCLUDE (1) INVERSE SQUARE LAW, (2) SOURCE CALIBRATION, (3) METER CALIBRATION, (4) RADIATION ABSORPTION, (5) RADIATION SCATTERING, (6) X-RAY MACHINE EMISSION RATE, (7) DARK ROOM PROCEDURES, (8) GAMMA RAY EXPOSURE CALCULATIONS, (9) X-RAY EXPOSURE CALCULATIONS, (10) EFFECT OF GRAININESS, (11) WELDED PIPE RADIOGRAPHY, (12) PANORAMIC EXPOSURES, (13) HIGH CONTRAST SUBJECTS, AND (14) LEAK TESTING SEALED SOURCES. (DH)

ERIC
Room 3013 FOB # 6
3006

ED020901

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
OFFICE OF EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL OFFICE OF EDUCATION POSITION OR POLICY.



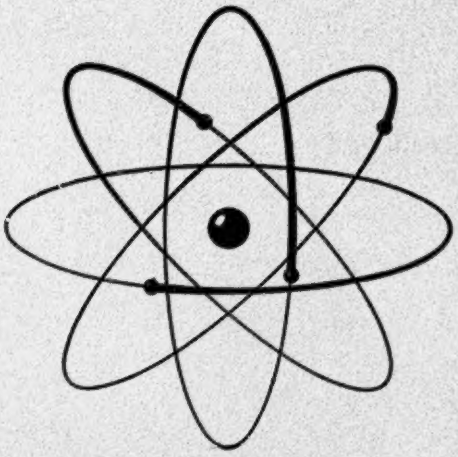
INDUSTRIAL RADIOGRAPHY
Instructor's Guide

SE004 883

DISCRIMINATION PROHIBITED—

Title VI of the Civil Rights Act of 1964 states "No person in the United States shall on the ground of race, color, or national origin, be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any program or activity receiving Federal financial assistance." Therefore, any program or activity making use of this publication and/or receiving financial assistance from the Department of Health, Education, and Welfare must be operated in compliance with this law.

OE-84034



INDUSTRIAL RADIOGRAPHY Instructor's Guide

Developed jointly by the Division of Vocational and Technical Education of the U.S. Office of Education and the Division of Nuclear Education and Training, U.S. Atomic Energy Commission.

Developed and first published pursuant to a contract with the U.S. Atomic Energy Commission by Harry D. Richardson.

U.S. ATOMIC ENERGY COMMISSION
GLENN T. SEABORG, *Chairman*
Robert E. Hollingsworth, *General Manager*

U.S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
JOHN W. GARDNER, *Secretary*
Office of Education
HAROLD HOWE II, *Commissioner*

March 1968

Superintendent of Documents Catalog No. FS 5.284:84084

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON : 1968

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402. Price 40 cents

Foreword

Industrial radiography is a vital factor in the growth of modern industry. The training of industrial radiographers is of extreme importance in meeting the needs of industry. They can assist in controlling production costs, assure product quality and reliability, and support other related aspects of production and product competitiveness.

This 80-hour course is designed to provide the basic knowledge and skills necessary for the beginning radiographer. A trainee in this course is expected to have a high school education. Using these fundamentals, he can further develop his knowledge and skills through shop and field experiences and additional study.

The lessons in the *Student Guide and Laboratory Exercises* are coordinated with the lessons in this *Instructor's Guide*. The subject matter selected from the *Industrial Radiography Manual* is presented in this Guide in a sequence different from that in the *Manual* to give variety to classroom sessions. This also permits laboratory exercises to be included in earlier class sessions. Although it is desirable for a radiographer to have knowledge of all the material in the *Manual*, the trainee cannot learn that volume of material during a limited 80-hour program. Appendix D in the *Manual* lists the paragraph numbers and their titles which are most important for the beginning radiographer to know. After mastering this material he should learn the remainder of the material in the *Manual* and its bibliography.

The instructor should have available copies of all items in the bibliography. Trainees should be encouraged to use these during their training programs and for continued studying after returning to their places of employment in order to become more knowledgeable and competent.

In addition to this *Instructor's Guide*, the material prepared and coordinated for this course includes *:

Industrial Radiography—Manual

Industrial Radiography—Student Guide and Laboratory Exercises

---

*Manual, *Industrial Radiography*, OE 84036, available from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, price $1.25.

Student Guide and Laboratory Exercises, *Industrial Radiography*, OE 84035, available from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, price 55 cents.

The need for this course was identified by officials in the U.S. Atomic Energy Commission. The Commission's first concern was to eliminate overexposures to workers engaged in radiography. A second interest was to increase the trained manpower in this expanding field. Content and format for the course were identified by a committee of industry representatives working with representatives of the U.S. Atomic Energy Commission and the U.S. Office of Education, Division of Vocational and Technical Education.

The writing of the manual was performed by Harry D. Richardson, Louisiana State University, under contractual arrangements with the Division of Nuclear Education and Training, U.S. Atomic Energy Commission.

GRANT VENN
Associate Commissioner for
Adult, Vocational, and Library Programs

RUSSELL S. POOR
Director, Division of
Nuclear Education and Training

Class Organization Plan

This Instructor's Guide is composed of lessons. Weighted times give relative emphasis to more important topics. Instructors are encouraged to discuss personal experiences and refer to radiography problems encountered in industry.

These lessons are coordinated with the Student Guide lessons and the Laboratory Exercises. The subject matter for the lessons is taken directly from the *Industrial Radiography Manual.* Other references listed in the bibliography should also be used.

Experience in teaching this material to radiography technicians indicates the students should be given ample classroom time to work numerous problems. Personal observation by, and the assistance of, the instructor are necessary to assure the student solves problems correctly. Preparing problems that realistically relate to shop and field situations holds the student's interest.

The Student Guide lessons should be completed by the student and given to the instructor. These lessons should be graded and returned to the student for filing in a notebook. Discussion of the lessons and the student's answers will provide follow-up review.

Announcement of written examinations has proved to be an impetus to the student's studying and diligence in class and laboratory work.

Contents

Page

FOREWORD iii

CLASS ORGANIZATION PLAN v

LESSONS 1

Introduction–Radiography Demonstration 1

1. The Structure of Matter and Radiation 3
2. Nuclear Reactions and Radioisotopes 7
3. The Nature and Consequences of Radiation Exposure 10
4. Radiation Attenuation 16
5. Absorption of Radiation 18
6. Radiation Detection and Measurement 21
7. The Effect of Radiation on the Organs and Tissues of the Body 25
8. Introduction to Radiography 29
9. Elements of Radiography 32
10. Radiographic Film 36
11. Radiography Techniques 40
12. Interpretation of Radiographs 43
13. Government Licensing, Health, and Transportation Regulations for Radiography 46

APPENDIX—Suggested Typical Examination 53

Introduction—Radiography Demonstration

TIME: One hour

OBJECTIVES:

1. To introduce the general subject of radiography.

2. To identify for the students the apparatus to be used during the training program.

APPARATUS:

1. A radiation exposure device, either X-ray or gamma ray. (No radiation exposure is desired in this demonstration so the isotopes should be left in storage.)

2. A "safety kit." (Refer to the laboratory experiments for this list of apparatus.)

3. Specimen to be radiographed. (A radiograph of this specimen should be available.)

4. Film holder and one sheet of film.

5. Lead screens.

6. Stop watch.

7. Measuring tape.

8. Lead letters and numbers.

9. Penetrameters.

10. Masking tape.

11. High intensity viewer.

12. Sample radiographs.

PROCEDURE:

The instructor will identify each piece of apparatus and very briefly describe its function in radiography operations. A "dummy" arrangement of apparatus will be used to demonstrate how an exposure is made. Items in the safety kit will be used to initiate student thinking and actions interrelating good radiation safety practices with industrial operations which use high intensity sources of ionizing radiation.

At the end of this demonstration, the student will be given course manuals and instructed on how to use the manuals to apply his time most advantageously during the entire training program.

The Structure Of Matter And Radiation

TIME: One hour

OBJECTIVES:

1. **To acquaint radiography students with the basic concepts concerning the structure of matter.**
2. **To develop a basic understanding of radioactivity and radiation.**
3. **To provide information about certain kinds of radiation machines.**

TEACHING AIDS:

1. **Chalkboard or chart pad.**
2. **Figure references from *Industrial Radiography Manual***
    - **a) Isotopes of Hydrogen (Fig. 1.7)**
    - **b) Identifying Three Common Types of Radiation (Fig. 2.1)**
    - **c) The Electromagnetic Spectrum (Fig. 2.3)**

REFERENCE:

***Industrial Radiography Manual*, Chapters 1 and 2.**

LESSON:

Introductory Statement:

Some basic understanding of the atomic structure of matter is necessary if the radiographer is to understand radiation and its application in industry. The study of radiation must begin with more basic concepts such as the fundamental particles, structure of the atom, isotopes, and elements, the basic building blocks of nature. There are 92 elements occurring naturally and others have been made by man. Many of these elements are radioactive. Others may be made radioactive. These emit various kinds of radiation through a process of radioactive decay until they reach a stable state and are no longer radioactive.

Teaching Outline:

I. The structure of matter

A. The atom and subatomic particles

1. **Electrons—small, very low weight particles—revolve around nucleus and carry unit negative charge.**
2. **Protons—relatively heavy particles compared to electrons, have a positive charge equal, but opposite, to that of electrons.**
    - **a) Number of protons in nucleus equals number of electrons in orbit about nucleus of normal atoms.**
    - **b) Number of protons in nucleus determines to what element species the atom belongs.**

        3. Neutrons—nearly identical to proton in size and weight but have no electrical charge; are bound in nucleus of atoms along with protons.

- B. The atom may be compared to the solar system (Fig. 1.2)* or electron cloud model (Fig. 1.5).
- C. Elements are composed of atoms
    1. These atoms have same number of protons in nucleus—this is known as the atomic number of the element.
    2. They have similar physical characteristics.
    3. There are 92 naturally occurring elements.
        - a) Hydrogen is the first element, having one proton in its nucleus.
        - b) Uranium is the last naturally occurring element and has 92 protons in its nucleus.
        - c) Transuranium elements 93 to 102 are man made.
- D. Compounds are composed of molecules.
    1. Atoms of different elements may combine to form molecules, the smallest unit of a compound.
    2. Two atoms of hydrogen and one atom of oxygen make a molecule of water (H_2O).
    3. Twelve carbon atoms, 22 hydrogen atoms, and 11 oxygen atoms compose a molecule of sugar ($C_{12}H_{22}O_{11}$).
- E. Atomic weight and isotopes
    1. Weight of one oxygen atom has been arbitrarily set at 16 units.
    2. Other elements have atomic weights in relation to the oxygen atom.
    3. The number of neutrons in the nuclei of atoms of same element may vary.
        - a) Atoms retain their same chemical characteristics but their atomic weight varies.
        - b) Isotopes of an element all contain the same number of protons but differ in number of neutrons.
        - c) The more neutrons the higher the atomic weight.
        - d) Most samples of an element secured by man are mixtures of isotopes of the element.
    4. Compare isotopes of hydrogen and uranium.
        - a) Common form of hydrogen atom has one proton and one electron.
        - b) Deuterium has one proton and one neutron in nucleus. Each isotope of hydrogen has one orbital electron (Fig. 1.7).
        - c) Uranium 238 has 92 protons, 146 neutrons, and 92 orbital electrons.
        - d) Uranium 235 has 92 protons, 143 neutrons, and 92 orbital electrons.

II. Radiation

- A. Excess energy possessed by unstable radioisotopes is emitted in the form of radiation (Fig. 2.1).

---

* References are taken from the *Industrial Radiography Manual.*

B. Two types of radiation are particulate and electromagnetic

1. Particulate radiation is the movement of subatomic particles through space
    - a) Alpha particles are nuclei of helium atoms having an atomic weight of 4, travel relatively slowly, and carry 2 positive charges. They travel only a few centimeters in air and will be stopped by a sheet of paper
    - b) Beta particles are high speed electrons having a range of several feet in air, and may be stopped by a few sheets of paper

2. Electromagnetic radiation consists of very short electromagnetic waves of energy having no charge or weight
    - a) This radiation has a wave quality and a particle quality
    - b) Gamma radiation has extremely short wavelengths, travels at the speed of light, is highly penetrating, and originates in nuclei of unstable atoms having excess energy
    - c) X-radiation is produced when a stream of high-energy electrons is slowed down upon striking a suitable target. Electron transitions between orbital shells give off photons of X-rays
    - d) Frequency x wavelength = speed of light
    - e) Electromagnetic spectrum ranges from long wave lengths (low energy) at one extreme to very short wave lengths (high energy) at the other extreme (Fig. 2.3).

III. Radiation machines

A. X-ray tubes have an electron generating filament and a target anode sealed in a high vacuum

1. Positive charge on anode attracts negative electrons
2. When electrons strike target and are slowed down they release energy in the form of X-rays
3. Also atoms in target acquire energy when orbital electrons are dislodged. The excited atom attracts free electrons and emits X-rays in returning to a stable state
4. X-ray tubes have a wide application in medicine and industry

B. Van de Graaff generator is an electrostatic straight line accelerator

1. Moving belt transfers charges to hollow metal sphere
2. The potential of several million volts is used to accelerate charged particles down a tube to a target

C. Linear accelerator makes use of a high frequency oscillator

1. Alternate cylinders are connected together and connected to the terminals of the oscillator

    2. Charged particles are accelerated across gaps between cylinders if cylinders are of correct lengths
    3. Electrons may be made to approach the speed of light

  D. Betatron is an electron accelerator which uses magnetic induction to accelerate electrons in a circular path
    1. Magnetic field is provided by large magnetic coils with a laminated iron core operating on 60 or 180 cycle alternating current up to 400 cycles
    2. Electron velocities acquire very high energy in a very short time

IV. Assign *Student Guide* Lesson 1.

Nuclear Reactions And Radioisotopes

TIME: One hour

OBJECTIVES:

1. To acquaint radiography students with basic concepts of nuclear reactions.
2. To develop basic ideas about the activation of isotopes.
3. To develop an understanding of the decay of radioactivity.

TEACHING AIDS:

1. Chalkboard or chart pad
2. Figure references from *Industrial Radiography Manual*
    - a) Chain Reaction of U–235 (Fig. 3.2)
    - b) Decay Schemes for Co–60 and Cs–137 (Fig. 3.8)
    - c) Decay of Radioisotopes (Fig. 3.5)
    - d) Co–60 Decay Curve: Cartesian Coordinates (Fig. 3.6)
    - e) Co–60 Decay Curve: Semi-Log Coordinates (Fig. 3.7)

REFERENCE:

Industrial Radiography Manual, Chapter 3.

LESSON:

Introductory Statement:

Efforts to secure nuclear energy became successful after Fermi used neutrons to bombard atoms of elements. It was found that such a bombardment caused *fission* or the breaking apart of heavy atoms into lighter atoms. Some of the fission products would be radioactive. At the same time enormous energy was released.

Frequently an atom would capture a neutron in its nucleus and become a radioactive isotope of the original element. These man-made radioactive isotopes play an important role in radiography today.

Radiographers need some concept of the decay of radioactivity and of radioactive half-life. Plotting radioactive decay is an important technique since this allows the person working with radioactive materials to know the amount of emission of a bit of such material at any given time.

Teaching Outline:

I. Nuclear reactions
    A. Nuclear fission
        1. Caused by neutron bombardment
        2. Binding energy holds atoms together
        3. Much energy released

4. Uranium atom may capture neutron
    a) U–238 changed to neptunium
    b) Neptunium is radioactive and decays to plutonium
    c) Plutonium fissions and releases more neutrons (Fig. 3.1)
    d) May cause chain reaction

B. Chain reactions

1. Fissionable isotopes include U–235, plutonium, thorium and protoactinium (Fig. 3.2)
2. Fissionable atoms split approximately into equal fragments (Fig. 3.3)
3. Many neutrons released in atom fission
4. Critical mass depends upon amount and shape of fissionable material

C. Fission products

1. Two groups of fission products are formed
2. These cluster around isotopes of mass numbers 90 and 140
3. Barium, krypton, strontium, and cesium are frequently formed
4. There is excess of neutrons

II. Activation of isotopes

A. More than 1500 isotopes known

1. Only a few naturally occurring radioactive isotopes
2. Large number of man-made radioactive isotopes

B. Early production methods used machines to shoot fast particles at atoms

1. Cyclotron was an early device
2. Alpha particles, protons and deuterons were used as bullets

C. Radioisotopes produced in nuclear reactors

1. Some radioactive products, produced by fission itself
2. Elements may be inserted in reactor and bombarded by neutrons

D. Activation of atoms

1. Number of target nuclei being activated may be represented by equation: $A = Nf\sigma t$ (par. 3–5)
2. Cobalt-59 may capture neutron and become radioactive cobalt-60. (Write equation on blackboard to show balancing mass and charge.)

III. Decay of radioactivity

A. Excess energy of nuclei of radioactive atoms emitted as radiation

1. Radiation is usually alpha and beta particles and gamma rays
2. Radioactive elements may decay in a series such as the thorium, uranium or actinium series

3. These series may involve numerous steps (Table 3.1)
4. Eventually a stable isotope is formed (par. 3–10) (Fig. 3.8)

B. Radioactive decay proceeds at a rate dependent upon total number of atoms present at a given time

1. Rate of decay constantly changes since number of atoms present is changing (Fig. 3.5)
2. Equation to represent decay takes the form $N = N_o e^{-\lambda t}$

where N = number of atoms remaining after time "t" (par. 3–7).
N_o = number of atoms present at zero time
e = base of natural logarithms = 2.718 . . .
λ = decay constant of the radioisotope
t = time

3. The radioactive half-life of an element is related to λ in the equation on the preceding page: half-life = $.693 \div \lambda$

C. The curie

1. Rate of disintegrations of a radioisotope is referred to as its *activity*
2. The unit of measure of activity is the *curie* which is the amount of any radioisotope that gives 3.7×10^{10} disintegrations per second
3. Millicurie and microcurie are commonly used as units of measure of activity: 1,000 millicuries equal 1 curie; 1,000 microcuries equal 1 millicurie

D. Plotting radioactive decay

1. Various kinds of instruments measure or count disintegrations
2. If the count or measure of activity is known along with the half-life for a given bit of radioactive material, a decay curve may be plotted (see Figures 3.6 and 3.7)
3. The measure of activity in curies may be plotted against time on cartesian coordinate paper or on semi-log paper (Figures 3.6 and 3.7)
4. Decay curve is a straight line on semi-log paper (Fig. 3.7)
5. Pass out cartesian coordinate paper and let students plot decay curve for a 32-curie source of Ir-192. Label the coordinates
6. Pass out semi-log coordinate paper and plot the same curve as for item 5 and label the coordinates. Place a legend on sheet to identify:
   a) Isotope
   b) Sealed source
   c) Source manufacturer
   (Student must plot curves during class and instructor will check to determine that the work is neat and correct.)

IV. Assign *Student Guide* Lesson 2

The Nature and Consequences of Radiation Exposure

TIME: One hour

OBJECTIVES:

1. To inform radiography students that the risks of radiation exposure are similar to many other risks which they face daily and are not to be unduly feared on the one hand or taken too lightly on the other.
2. To acquaint radiography students with the standard measurement units of radiation doses.
3. To acquaint radiography students with permissible radiation exposures and inform them how these standards relate to personnel monitoring.
4. To inform radiography students about additional aspects of personnel monitoring, including physical examinations, instrumentation and contamination.
5. To introduce the separate problems of external and internal radiation exposure.
6. To inform radiography students of the different levels of radiation injury and to acquaint them with the basic symptoms characteristic of each level.

TEACHING AIDS:

1. Chalkboard or chart pad.
2. Figure references from *Industrial Radiography Manual*
   a) Pie chart—Estimated Average Annual Gonad Exposures in the U.S. (Fig. 6.1)
   b) Chart—Radiation "Banking" Concept for Radiation Workers (Fig. 6.3)

REFERENCE:

Industrial Radiography Manual, Chapter 6.

LESSON:

Introductory Statement:

The major purposes of this lesson are to give students a perspective for understanding radiation hazards in terms of other hazards of life and to introduce them to certain technical terms related to the measurement and symptoms of radiation injury. In the first instance it should be made clear that all human activity involves certain risks, physical or mental. For example the bridge builder, the electrician, etc., face constant danger of physical injury, while the harried business executive or striving professional man is subject to mental breakdowns. The point of stress is that these risks are commonly accepted and do not loom as important considerations to persons aspiring to become bridge builders, electricians, business executives or various types of professionals. The student should be convinced that each occupation has its peculiar hazard and that radiation hazard, when known and understood, can be minimized or completely avoided.

Radiography students in their future roles as technicians must have a degree of professionalism with regard to radiation. To this extent they must become familiar with technical terms relating to the measurement of radiation exposure and injury as well as those relating to radiation physics and industrial radiography. In addition, a knowledge of the gross effects of radiation injury provides the student with a frame of reference for understanding and appreciating the problem of personnel monitoring and contamination.

Teaching Outline:

I. Radiation hazard in proper perspective

  A. Philosophy of risk evaluation

    1. Radiation hazards should not be unreasonably feared or completely ignored
    2. Most persons accept hazards in their work or other activities as a matter of course
      a) Electricians, bridge builders, miners, farmers, etc.
      b) Records of National Safety Council show that all modes of transportation present hazards
      c) Many accidents occur in the home or at play, such as falling downstairs or hunting accidents

  B. All persons are constantly being exposed to some radiation

    1. "Background" radiation occurs in nature
      a) Cosmic radiation from outer space—altitude accounts for the fact that the level of such radiation is twice as high in Denver as New York
      b) There are radioactive materials in the earth, some of which are transferred to building materials
      c) Radioactive materials are present in the body, which have been introduced in small amounts by food, water and air
    2. Man-made sources
      a) Medical devices, such as X-ray machines, are justifiable
      b) Industrial machines are also justifiable
      c) Fluoroscopes for fitting shoes, etc., represent exposure having questionable value (Fig. 6.1)

  C. Sources of information about radiation's effect on man

    1. Animal experiments—major disadvantage is that dose-effect relations cannot be assumed to be the same
    2. Occupational experience
      a) Some workers received small doses of X and gamma

rays before full effects were known. The symptoms and injuries of these persons were studied.

   b) Persons working with medical and industrial machines have also been studied.

3. Medical uses—persons diagnosed or treated with radiation have been carefully studied over a period of time.
4. The atomic bombs
   a) The Hiroshima and Nagasaki bombs provided an opportunity to study effects of different levels of radiation over a period of time.
   b) The Bikini bomb tests also provided such an opportunity.

D. Radiation risk to radiographers must be evaluated in light of preceding discussion.

   1. The proper conclusion is that radiation can be dangerous if received in sufficient quantity.
   2. With proper care, people can work with radioactive materials without any apparent effect on their ability to continue living a normal life.

II. Measurement units of radiation doses

A. It is impossible to measure a quantity of radiation directly since it can bring about a change in matter only to the extent of the energy actually absorbed.

   1. A given biological effect may also depend upon the type and energy of the radiation.
   2. For these reasons, it is more convenient and practical to measure exposure in purely physical terms and to use an additional factor to allow for relative biological effectiveness.

B. Measurement terms

   1. Roentgen
      a) A unit for measurement of penetrating external radiation (gamma) as it passes through air.
      b) Defined as—the quantity of X or gamma radiation that will produce one electrostatic unit of charge, either negative or positive, in one cubic centimeter of air at standard temperature and pressure (0°C and 760 mm Hg)
      c) The roentgen can be sub-divided into a more convenient unit, the milliroentgen. 1,000 milliroentgens equal 1 roentgen.
   2. Rem (roentgen equivalent man)
      a) Since the roentgen measures radiation in air only, the rem is used to define biological effects on man. The rem is used to measure radiation dose produced upon living tissue. (See par. 6-6.)
      b) One roentgen of X or gamma radiation upon striking the body produces a dose of one rem of bodily damage.
      c) The rem can be sub-divided into more convenient

units called millirem (mrem) which is one/thousandth of a rem.

3. Rad (Radiation absorbed dose)
    - a) Defined as amount of radiation imparted to matter by an ionizing particle per unit mass of irradiated material
    - b) The dose unit, the rad, represents an absorption of 100 ergs of energy per gram of irradiated material at the place of exposure
4. RBE (Relative biological effectiveness)
    - a) Values of RBE have been worked out based on the X-ray as an RBE of one
    - b) Values of RBE have been worked out for all sources of radiation for computing total exposure from a given dose. (See par. 6–3.4)
    - c) Problem to be copied from text

III. Nature of Radiation Health Problem

A. External radiation

1. Radiation being given off by certain radioactive materials located outside of the body
2. Can be visualized as a shower of tiny bullets

B. Internal radiation

1. Results from radioactive materials getting into the body
2. These materials tend to collect in certain body organs and cause damage
    - a) Biological half-life
    - b) Effective half-life

IV. Levels and Symptoms of Radiation Injury

A. Classification of doses of radiation

1. Mild dose
    - a) Exposure up to 25–50r
    - b) Produces no detectable clinical effects.
2. Moderate dose
    - a) 25r to 100–200r
    - b) Produces some but not excessive damage (blood changes, vomiting, diarrhea, loss of appetite)
3. Median lethal dose
    - a) 200–300–400r
    - b) Injury and disability certain, possibility up to 50% mortality (drastic blood damages, anemia, sterility, epilation)
4. Lethal dose
    - a) 300–600r or more
    - b) Death usually occurs in less than two weeks.

B. Common terms used to describe gross effects or radiation injury

1. Radiation sickness
    - a) Produced by a *massive overdose* of highly penetrating

external radiation to the whole body or a substantial portion of the body

        - b) Causes nausea, vomiting, diarrhea, hemorrhage, and lowering of the body's resistance to infection
    - 2. Radiation injury
        - a) Produced by an overdose of external radiation to localized portion of the body
        - b) Can cause injuries such as skin lesions and loss of hair
    - 3. Radioactive poisoning
        - a) Produced by dangerous amounts of certain types of radioactive materials introduced into the body by breathing or swallowing or through wounds in the skin
        - b) Can cause such diseases as anemia and cancer

V. Personnel monitoring (Chapter 13 presents Federal regulations, to be explained in detail at a later time, which govern all industrial installations using byproduct materials.)

- A. Permissible Exposure—that dose of ionizing radiation which competent authorities have established as the maximum that can be absorbed without undue risk to human health
    - 1. Permissible occupational dose to whole body, accumulated at any age, shall not exceed a total of 5 rem multiplied by the number of years beyond the age of 18
    - 2. These recommendations are intended to protect the individual and total population against both immediate and delayed radiation induced injury
- B. Radiation "Banking" Concept (Fig. 6.3)
    - 1. Permissible rate of exposure set in accordance with what is known as radiation "banking" concept
    - 2. Consider that each man has a radiation account to which he adds 5 rem each year of his life after 18. He can draw on this account at the rate of 12 rem per year.
    - 3. (Discuss all details of Fig. 6.3.)
- C. Unusual exposure
    - 1. A person may be submitted to unusual exposure for several different reasons
        - a) Non-continuous exposure—a person is allowed to receive more exposure than recommended levels per day or week provided no further exposure is sustained for a recommended period.
        - b) Fractional exposure—certain parts of the body such as the hands and forearms are permitted to receive larger doses of radiation.
        - c) Excessive exposure
            - (1) If an individual receives exposure greater than 100 rem in less than 10 years, he will have to work under conditions of low or no radiation to prevent bodily injury.
            - (2) The National Committee on Radiation Protec-

tion and Measurement (NCRP) recommends that once-in-a-lifetime whole body emergency or accidental exposure of 25 rem may be received. Although this exposure is not charged against a person's total permissible occupational dose, it should purposefully be received only in extremely important or emergency situations.

    - d) Medical diagnostic exposures are exempt from calculation of maximum permissible occupational exposure.

D. Physical examinations
  1. Pre-employment exam
    - a) Designed to eliminate abnormally radio-sensitive individuals
    - b) Desirable for work with radioactive materials
  2. Follow-up physical
    - a) Designed to assure that maximum permissible levels of exposure have not been exceeded
    - b) Afford a way of keeping track of the ability of the body to respond to damage

E. Instrumentation
  1. Human inability to detect radiation makes mechanical means of monitoring essential
  2. Personnel monitoring devices are therefore required by law

F. Contamination
  1. Contamination hazards
    - a) Any contamination may find its way into the human body. Alpha and beta emitters are more hazardous internally because of their short range. Alpha and beta emitters are not usually considered to cause external hazards.
    - b) Gamma emitters present hazards externally as well as internally.
  2. Safety precautions
    - a) New personnel should be made fully aware of safety devices and emergency procedures
    - b) Exposed parts of body and clothing should be monitored frequently
    - c) Thorough searches should be made for contamination at frequent intervals
    - d) Personnel should be forced to make a habit of cleanliness and should thoroughly wash exposed parts of their bodies during the work day and before leaving area
    - e) All persons responsible for radioactive materials should be thoroughly familiar with National Bureau of Standards Handbook 48.

VI. Assign *Student Guide* Lesson 3.

Radiation Attenuation

TIME: One hour

OBJECTIVES:

1. To develop understanding and use of the inverse square law.
2. To study factors related to attenuation of radiation.
3. To present factors affecting radiation exposures.

TEACHING AIDS:

1. Chalkboard or chart pad.
2. Figure references from *Industrial Radiography Manual*
   - a) Variation of Radiation Intensity with Distance from Source (Fig. 4.4)
   - b) Dose Rate of Commonly Used Radioisotopes (Table 4.1)

REFERENCE:

Industrial Radiography Manual, Chapter 4, par. 4–4 and 4–5; Chapter 6, par. 6–3.

LESSON:

Introductory Statement:

In radiography the source of radiation may, for practical purposes, be considered a point source. In this case, the intensity of radiation is inversely proportional to the square of the distance from the source. The inverse square law applies not only to radiation from radioactive materials but to all electromagnetic radiation such as radiowaves and light.

The effect of time on radiation exposure may be understood in terms of the definition of dose-rate in roentgens per hour (r/hr) or milli-roentgens per hour (mr/hr). If a radiographer works where the radiation intensity is 50 milli-roentgens per hour, then in one hour, he would get 50 milli-rems of exposure and in two hours he would get 100 milli-rems of exposure.

Teaching Outline:

I. Time is a factor in radiation exposure

   A. Roentgen is a measure of the ionizing effect of radiation on air.

      1. The roentgen measure a definite amount of gamma or X-radiation.
      2. Dose rate is expressed in roentgens per hour or milliroentgens per hour.

B. The rem (roentgen equivalent man) is the amount of body dose produced by one roentgen of penetrating external radiation. (See par. 6–6.)
If exposure time is doubled the rem or body damage is doubled.

II. Distance and the attenuation of radiation

A. Radiation decreases as the square of the distance from source (Fig. 4.4).

B. The inverse square law $\frac{I}{I_o} = \left(\frac{d_o}{d}\right)^2$

Where: I = radiation intensity at distance d
d = distance at which intensity is I
I_o = radiation intensity at distance d_o
d_o = distance from source to point at which radiation intensity is I.

C. Finding radiation intensity when distances are known

If the radiation intensity, I_o, is known at distance d_o then the radiation intensity at distance d, is found by solving:

$$I = \frac{I_o \times d_o^2}{d^2}$$

Solve an example for the students (par. 4–5). Assign a problem for students to solve in class. (The instructor will observe individual students at work.)
(Sources of radiation used by radiographers have a dose rate given in roentgens per hour per curie at 1 foot.)

D. Finding the intensity of radiation at a specified distance from a known source: Solve an example for the students (par. 4–5). Assign a problem for students to solve in class. (The instructor will observe individual students at work.)

E. Finding the distance from a specified source at which radiation will be attenuated to some desired value: Solve an example for the students (par. 4–5). Assign a similar problem for students to solve in class. (The instructor will observe individual students at work.) (If needed, use the Table of Squares and Square Roots in the *Manual,* Appendix C.)

III. Assign *Student Guide* Lesson 4.

Absorption of Radiation

TIME: One hour

OBJECTIVES:

1. To acquaint radiography students with the absorption characteristics of the various types of radiation.

2. To develop an understanding of the absorption of gamma rays in shielding.

3. To familiarize students with the half-value layer concept.

4. To present the concept of reduction factors.

TEACHING AIDS:

1. Chalkboard or chart pad.

2. Figure references from *Industrial Radiography Manual*
   - **a) Absorption of Radiation (Fig. 4.5)**
   - **b) Half-Value Layers (Fig. 4.8)**
   - **c) Relative Efficiency of Shielding Materials (Fig. 4.9)**
   - **d) Broadbeam Radiation Reduction Factors (Figs. 4.10, 4.11, 4.12)**

REFERENCE:

***Industrial Radiography Manual*, Chapter 4**

LESSON:

Introductory Statement:

Of the types of radiation emitted by radioisotopes, gamma rays are of most interest to radiographers. Gamma rays can penetrate the most dense materials and are not wholly stopped by any absorbing material. The intensity of gamma rays traversing an absorbing material plotted against the thickness of the absorbing material gives an exponential curve (Fig. 4.8).

There is little use in trying to compute the amount of absorbing material needed to stop all gamma or X-radiation, since a point is never reached where all such radiation is stopped. It is convenient to employ the concept of using adequate shielding to reduce the radiation intensity to values that are acceptable for industrial workers.

The use of half-value layers and reduction factors gives suitable results for designing shields for industrial radiography.

Teaching Outline:

I. The absorption of radiation
   - **A. Alpha and beta rays may be stopped (Fig. 4.5).**

B. Gamma and X-rays are not completely stopped by shielding.
   1. The intensity of X or gamma rays after passing through an absorber may be computed by the equation:

$$I = I_0 e^{-\mu t}$$

      where I_0 = initial intensity of gamma rays
      e = base of natural logarithms
      μ = linear absorption coefficient of absorber for given gamma rays
      t = thickness of absorber in centimeters
   2. Intensity of radiation plotted against thickness of absorber gives exponential curve
      a) Study chart showing curve on cartesian coordinate paper (Fig. 4.6).
      b) Study chart showing curve becomes a straight line on semi-log coordinates (Fig. 4.7).

C. Linear absorption coefficients
   1. Absorption coefficients vary with the energy of the radiation.
   2. Also, absorption coefficients are affected by the atomic number of the absorber.
   3. Study Table 4.2 and note changes in coefficients with changes in energy of gamma rays and changes in materials.
   4. Demonstrate use of table of absorption coefficients in a problem.
   5. Show plot of radiation intensity against thickness of absorber on cartesian and semi-log paper.

II. Half-value layers

A. A half-value thickness is that thickness of absorber necessary to reduce radiation intensity to half its initial value.
   1. A half-value thickness is related to the linear absorption coefficient by the following equation:

$$\text{HVL} = \frac{0.693}{\mu}$$

      where HVL = half-value thickness (centimeters)
      μ = linear absorption coefficient.
   2. Compute half-value thickness for lead and water at some given value of energy for gamma rays, e.g., 0.1, 0.5, and 1.0 Mev (Table 4.2 and Fig. 4.8)

B. The half-value layer idea may be used to work practical problems in shielding (par. 4–7) (Fig. 4.9).
   Assign a problem for students to solve in class. (The instructor will observe individual students at work.)

III. Reduction factor

A. A reduction factor is the dose rate of radiation reaching a point at some distance from a source divided by the dose rate reaching the same point with some shield interposed.

B. $$\text{Reduction factor} = \frac{\text{dose rate without shield}}{\text{dose rate with shield}}$$

1. Reduction factor for a given radioisotope may be plotted against thickness of a given shielding material.
2. Such a graph may be used to compute shielding thickness in practical problems (p. 35) (Figs. 4.10–4.12).

IV. Principles of Radiation Safety (Figure 4.13)

A. Personnel dosage is directly related to exposure time.

$$\text{Allowable working time in hr/week} = \frac{\text{permissible exposure in mr/wk}}{\text{exposure rate in mr/hr}}$$

B. Lower personnel dosage will be received at longer distances from a source. This is an application of the Inverse Square Law (Table 4.3)

C. Shielding interposed will reduce personnel dosage.

D. Many industrial radiation safety problems will require combinations of, or all of, the factors: (1) TIME, (2) DISTANCE, and (3) SHIELDING.
Assign a similar problem for students to solve in class. (The instructor will observe individual students at work.)

V. Assign *Student Guide* Lesson 5.

Radiation Detection and Measurement

TIME: One hour

OBJECTIVES:

1. To develop a basic understanding of radiation detection and measurement.

2. To learn basic concepts of radiation measuring instruments.

3. To familiarize students with the more commonly used radiation measuring instruments required for industrial radiography.

TEACHING AIDS:

1. **Chalkboard and chart pad.**
2. **Figure reference from *Industrial Radiography Manual***
   The Pocket Dosimeter (Fig. 5.2)

REFERENCE:

***Industrial Radiography Manual*, Chapter 5.**

LESSON:

Introductory Statement:

Radiation emitted from radioactive materials and X-ray machines cannot be detected by the human senses. Therefore, some kind of instrument must be used to determine the presence of radiation. Except for photographic film techniques, almost all radiation detecting devices used by radiographers are based upon the ionization in a gas through which the radiation passes. These devices help provide protection to personnel from radiation exposure and are necessary in making measurements related to radiography.

Teaching Outline:

- **I. Detection and measurement of radiation**
  - **A. *Detection* is the determination of the presence of radiation.**
  - **B. *Measurement* includes both detection and some measure of the amount of radiation.**
  - **C. Total dose exposure may be measured.**
    - **1. One type of instrument measures the accumulated exposure to radiation over a period of time. This is called a *dosimeter*.**
    - **2. The milliroentgen is frequently used for measuring total dose exposure.**
    - **3. Examples of dosimeters include: Lauritsen electroscope, the pocket dosimeter, the R-meter, and the film badge.**
  - **D. Dose-rate of exposure may be measured.**

1. **Instruments used to measure dose-rate exposure are called *survey meters.***
2. **Milliroentgens per hour is a commonly used measure for dose rate.**
3. **Examples of survey meters include the Geiger counters and the ionization chambers as detectors.**

II. **Dosimeters**

A. **Lauritsen electroscope**
   1. **Is an ionization chamber instrument with a closed chamber for collecting ions formed by radiation**
   2. **Chamber contains insulated electrode that has a fixed and a movable part**
   3. **When electrode is charged the movable part is deflected from the fixed part**
   4. **As ions in chamber are formed by radiation, those with a charge opposite to electrode travel to it**
   5. **As ions neutralize charge on electrode the movable part is deflected less and furnishes a measure of amount of ionization and therefore of radiation**
   6. **A movable quartz fiber is viewed through a transparent scale and the amount of deflection can be measured**

B. **Pocket dosimeter (Fig. 5.2)**
   1. **Essentially a Lauritsen electroscope modified to about the size of a fountain pen**
   2. **May be obtained to read in roentgens and milliroentgens**
   3. **Direct reading type can be held up to light to see the hairline which moves across a scale, indicating dosage received**
   4. **Nondirect reading type must be inserted in a reading device to indicate dosage received. These are called pocket chambers**
   5. **Due to insulator leakage, these devices are likely to give readings higher than the actual radiation received.**

C. **R-Meter**
   1. **Is an ionization type instrument made in a variety of styles**
   2. **Composed of a small chamber or roentgen meter and an instrument for charging and measuring exposure of the small chamber**

D. **Film badges (Dismantle a film badge and film packet. Describe and allow students to examine all the parts.)**
   1. **Consists of small piece of X-ray film in a metal holder**
   2. **Is worn on outer clothing**
   3. **Measures gamma and X-radiation and high energy beta radiation**
   4. **Film must be developed by controlled techniques and compared to a set of control films to determine amount of radiation received**
   5. **The film is darkened in proportion to amount of radiation received**

III. Survey meters

A. Ionization chamber instruments

1. Ions in a gas caused by radiation move to electrodes of opposite charges.
2. Electrodes are connected to a battery or other source of voltage.
3. Ions give up charges and cause a small current flow through battery and external circuit.
4. Current flow can be measured and thus give a measure of the radiation intensity required to produce the ionization.
5. Provide instantaneous measure of radiation intensity
6. May read up to 500 roentgens per hour

B. Geiger counter

1. Usually measures low intensities of radiation (milliroentgens per hour) (Special designs permit higher ranges.)
2. Uses a tube with high voltage and low gas pressure to increase sensitivity
3. One photon or particle entering the tube may start an avalanche of ions which will produce a voltage pulse. These pulses, through proper circuits, allow indication of radiation received on galvanometer or audible signals.
4. May be used to read gamma, X, and beta radiation.
5. Geiger counters may block out in a very high radiation field (special circuit designs can prevent this) and give no reading.

IV. Instrument Characteristics and Calibration

A. Characteristics of radiation measuring instruments should be considered.

1. Should detect desired radiation
2. Should cover suitable range of dose or dose rate of radiation
3. Should hold calibration
4. Should have a suitable time constant
5. Batteries should be easily available
6. Manufacturer should maintain good repair service

B. Radiographers need to calibrate instruments.

1. Must secure a source of radiation of known intensity (Use radiography source and manufacturer's calibration curve.)
2. Place instrument at distance to secure a certain reading.
3. Make manual adjustments on instrument as directed in the instrument manufacturer's instructions.
4. Work an example for the class similar to illustrated instrument calibration (par. 5–6).

V. Source Calibration (Fig. 5.6)—for making radiography exposure calculations and safety calculations it is mandatory that source emission rates be known. The process for determining this is called calibration and is accomplished according to this outline:

A. Place a dosimeter at a measured distance from the source.

B. Expose the source for a measured time.

C. By calculations in par. 5–7, determine the dose-rate at 1 foot from the source.

D. Divide the result in step 3 by the source emissivity (Table 4.1) Assign a similar problem for students to solve in class. (The instructor will observe individual students at work.)

E. Plot a source calibration curve similar to Fig. 5.6. (Be sure to label all parts of the curve sheet and identify the source.) Assign a similar problem for students to solve in class. (The instructor will observe individual students at work.)

VI. Assign *Student Guide* Lesson 6.

The Effect of Radiation on the Organs and Tissues of the Body

TIME: 30 minutes

OBJECTIVES:

1. To acquaint the radiography student with the effect of radiation on living matter.

2. To inform radiography students of the relative sensitivity of various body cells to radiation.

3. To develop an understanding of the types of biological effects of radiation and the factors related to these effects.

4. To acquaint the radiography student with the specific effect of radiation on the various organs and tissues of the body.

5. To familiarize radiography students with the genetic effects of radiation and the effect of radiation on the life span.

TEACHING AID:
Chalkboard

REFERENCE:
***Industrial Radiography Manual*, Chapter 7.**

LESSON:

Introductory Statement:

This lesson is designed principally for information purposes. It contains material with which the radiography student should be acquainted but which is not vital to the performance of his duties. The first point to stress is that radiation affects living matter principally by altering the ability of cells of the body to function normally. It should be made clear that the various cells of the tissues and organs are not affected in the same way. This fact explains why exposure of certain parts of the body can be considerably more critical in terms of injury than exposure of other parts. The student will have heard of the effect of radiation on the reproductive organs and may have undue fears founded on misinformation. He should be aware that radiation can and does produce genetic effects. There is evidence that radiation dosage shortens the life span. However, the available evidence does not warrant undue fear of these consequences because of the high dosages required to produce measurable effects compared to dosages likely to be received while working as an industrial radiographer.

Teaching Outline:

- **I. Radiation effects on living matter**
  - **A. The body of man is composed of cells.**
    - **1. Cells are the fundamental unit of structure of living**

organisms, just as the atom is the fundamental unit of chemical structure.

   2. A cell may be defined as "a restricted mass of protoplasm differentiated into cytoplasm, nucleus and a bounding membrane."

B. Bodies of living organisms have varying tolerances to all kinds of injuries or abuses.
   1. The body is able to repair damages to itself through a complicated process termed *mitosis*.
   2. Mitosis may be defined as a process whereby cell division takes place and worn out or damaged cells are replaced.

C. It has been determined that radiation affects the living organ principally by altering the ability of cells to function normally.
   1. This alteration comes about through the process of ionization.
   2. The electrical charge of irradiated atoms in body cells is changed and valence bond binding atoms into molecules is affected in such a way as to cause chemical interactions. (See par. 7–6.)

D. Effects of radiation include:
   1. Cell to continue to grow until it reaches an abnormal size
   2. Cell is altered so that its daughter cell is genetically different from it
   3. Daughter cells may die before they reproduce or divide at a higher or lower rate than parent cells.

E. In summary, the effect of radiation on a living organism is produced at the cell level and is both physiological and chemical in nature. The degree of damage depends on many conditions and factors.

II. Radiosensitivity

A. Defined as the difference in response of the different tissues and organs of the body to radiation
   1. Body cells which are more active in reproducing themselves and which are not fully mature are harmed most by radiation.
   2. This fact can be explained in terms of the higher metabolic rate (rate of chemical change) of these cells, which lowers their resistance.

B. Classification of body cells in order of radiosensitivity.
   1. Lymphocytes (white blood cells formed in the tissues of the spleen and lymph nodes, etc.) are the most sensitive.
   2. Granulocytes (white blood cells formed in bone marrow)
   3. Basal cells (originators of the more complex cells of the gonads, bone marrow, skin and alimentary canal)
   4. Alveolar cells (long cells which absorb oxygen from the air)
   5. Bile duct cells (important in digestion)
   6. Cells of the tubules of the kidneys
   7. Endothelial cells (which cover the closed cavities of the body)

    8. Connective tissue cells (which support the organs and specialized tissues of the body)
    9. Muscle cells
    10. Bone and nerve cells
  C. Factors related to somatic radiation effects (those experienced by the irradiated individual)
    1. The rate at which the dose is administered
      a) Body repair can keep up with damage to a point.
      b) Same dose over a shorter period of time would cause greater damage
    2. The extent of the body irradiated—whole body radiation is more harmful than radiation to a fractional part of the body.
    3. The part of body irradiated
      a) Certain portions of the body are more radiosensitive
      b) The upper abdomen generally highly radiosensitive
    4. The age of the individual—young persons are more susceptible than mature adults, because their body cells are in an accelerated stage of reproduction.
    5. Biological variation among individuals—some persons are more resistant to radiation because of the make-up and functioning of their bodies.

III. The effect of radiation on various tissues and organs of the body
  A. The blood and bone marrow—radiation impairs the functions of the blood so as to:
    1. Make the body more susceptible to disease
    2. Prevent blood clotting and thus prolong the healing of wounds
    3. Bring on serious pathological conditions because the ability of blood to carry food and waste products is impaired
  B. The lymphatic system (Lymph is the liquid which bathes all the cells of the body and transfers food and wastes from the blood.)
    1. Radiation which injures the spleen and other lymphatic tissue stops the production of lymphocytes and impairs the filtering of foreign substances out of the lymph.
    2. This impairment is associated with increased bacterial activity and reduces chances of recovery.
  C. Skin and hair follicles
    1. Rather large doses of irradiation are usually necessary for permanent damage, although skin reaction is one of first clinical indications of radiation exposure.
    2. Large doses of irradiation result in skin cancer and temporary baldness.
  D. The digestive system
    1. Radiation impairs the secretion of digestive juices and the reproduction of cells.
    2. Symptoms include vomiting, diarrhea and ulcers.
  E. The liver and gall bladder—radiation damage impairs ability of these organs to function as part of the digestive system and in the metabolism process.
  F. The endocrine system

1. **Radiation serves to make this system function less efficiently and to make the body more susceptible to heat, cold, injury and infection because the adrenaline supply cannot be replaced sufficiently.**
2. **Damage to thyroid gland decreases thyroxin production and affects the basal metabolism rate.**
3. **Damage to the gonads (reproductive organs) can produce sterility, although this is unusual, except for near lethal doses. Under modern conditions of occupational exposure, there is no danger of sexual impotency.**

G. The respiratory system—
Radiation produces effects on the lungs by damaging the air sacs; the lungs are especially susceptible to internal radiation, originating from air particles.

H. The urinary system—radiation damage can cause the cells of the uterus and bladder to break down and block the urinary tubes (uteres). One symptom is *tenesmes* (the urge to rid oneself of waste products without being able to do so).

I. The bones.

1. **Radiation presents a serious threat to the highly radiosensitive red bone marrow cells**
2. **Tumor production is also possible under certain conditions of internal radiation.**

J. The eyes—radiation affects the eyes by promoting the development of cataracts.

IV. Other effects of radiation.

A. Effect of radiation on the life span.

1. **Experiments on animals indicate radiation can affect the life span.**
2. **Careful analysis of all evidence available suggests that exposure to permissible occupational dose rates, even from an early age, does not shorten life.**

B. Genetic effects of radiation.

1. **Radiation can produce mutations.**
2. **Because of inadequate evidence, it is difficult to appraise genetic effects on (a) the individual or (b) the population as a whole.**
3. **The fear expressed that radiation would increase the frequency of abnormal births has not been validated by the Japanese bomb victim experience.**
4. **It is recommended that persons who receive radiation doses to their reproductive organs wait for a period of six months before conception of a child. This period permits the formation of sex cells which contain proportionally fewer gene mutations.**

V. Assign *Student Guide* Lesson 7.

Introduction To Radiography

TIME: 30 minutes

OBJECTIVES:

1. To introduce the student to the process of radiography.
2. To acquaint the student with the procedures required in the making of an industrial radiograph.
3. To inform students of the industrial applications of radiography.
4. To introduce certain terms and topics of importance to industrial radiography.

TEACHING AIDS:

1. Chalkboards and/or chart pads.
2. Figure reference from *Industrial Radiography Manual*
   a) Radiograph Exposure Arrangement (Fig. 8.1)
   b) Sample radiographs (to be prepared or obtained by the instructor)

REFERENCE:

Industrial Radiography Manual, Chapter 8.

LESSON:

Introductory Statement:

This chapter is designed to serve as an introduction to the more detailed discussions of radiography which follow. Its major purpose is to give the student an overall grasp of the process and purpose of industrial radiography and to present certain terms which are basic to the understanding of radiography. The last part of the chapter outlines the basic topics to be treated in depth in following chapters.

Teaching Outline:

I. Introduction
   A. Roentgen, a German, experimented with cathode rays in 1895.
      1. He discovered a new ray which caused a chemically coated paper to glow.
      2. This ray could penetrate paper, wood, metal, etc.
      3. The ray also affected photographic plates.
   B. The new ray was called the X-ray.
   C. In 1898 the Curies discovered that radium was radioactive.
      1. The invisible ray given off by radium was called a gamma ray.

    2. No use was made of radium as a source of radiation for radiography until the 1920's.
  - D. Later the Atomic Energy Commission produced and implemented distribution of artificially produced gamma ray sources.

- II. The process of radiography (Fig. 8.1)
  - A. Radiography is a process of testing materials which uses penetrating radiation such as X-rays or gamma rays.
    1. This allows the examination of the interior of objects or assemblies which are invisible to the eye.
    2. This radiography process is called non-destructive testing since objects are not damaged.
  - B. In radiography, the rays passing through the material are absorbed or changed.
    1. Change varies with the thickness and atomic number of material.
    2. As a result, the intensity of the radiation beam emerging from the object varies from point to point.
    3. Some kind of detector, such as a Geiger counter, films or fluorescent screen can be used to detect radiation.
  - C. Industrial radiography is concerned only with recording "shadow" images of specimens on film. These "shadows" result from differential radiation absorption in a specimen and discontinuities.
    1. The three basic essentials in producing a radiograph are:
       - a) A source of radiation
       - b) An object to be tested
       - c) A cassette containing film
    2. Radiation proceeds in a straight line and the amount reaching the film in the cassette depends on a number of factors, i.e., radiation source emissivity, radiation energy, source to film distance (SFD), and specimen absorptivity.
    3. Voids or breaks in steel, for example, can be detected because more radiation passes through these spots and makes a dark spot on the film.

- III. Applications of radiography include:
  - A. Testing and inspecting products of various kinds to determine soundness
  - B. Inspection of welds on high pressure or high temperature apparatus
  - C. Examination of castings
  - D. Inspection and examination of nonmetallic materials such as plastics, ceramics, concrete, paper, wood, textiles and food products
  - E. Pipe wall thickness measurements
  - F. Other types of radiography, such as:
    1. High speed or flash radiography
    2. Microradiography
    3. Stereography

IV. The radiograph

   A. The processed film containing the visible images caused by exposure to radiation is called a radiograph.
   B. The darkening of the radiograph is called *density.*
   C. Differences in density from one area to another are called *radiographic contrast.*
   D. Sharpness of outline in the image on a radiograph is called *definition.*
   E. Radiographic screens are used to shorten exposure time.—Such screens are called intensifying screens and are discussed in detail elsewhere.
   F. The contrast of radiographs may be reduced by *scatter.*
      1. Materials not only absorb but scatter radiation in all directions.
      2. The film thus receives radiation from the specimen, walls and floors of rooms, etc., which may tend to make the image hazy, unless reduced by screens, masks, diaphragms or filters.

V. Industrial radiography involves four basic topics (to be discussed in detail later).

   A. The source of radiation—including maximum energy of source and emission rate of source
   B. The specimen to be examined—including the mass density of the material, atomic number, composition and thickness of absorption path
   C. The film to be used—including speed and ability of film to resolve images
   D. Geometric principles—includes source size, source to film distance, specimen dimension and shape, specimen to film distance, and projected images

VI. Assign *Student Guide* Lesson 8.

In addition to these outlined principles, every successful radiographer must know and practice these topics:

1. Radiography techniques
   a) Exposure calculations
   b) Exposure arrangements
2. Interpretation of radiographs

Elements Of Radiography

TIME: One hour

OBJECTIVES:

1. To acquaint the student with the production of and characteristics of X-radiation.
2. To acquaint the student with the characteristics of gamma ray sources.
3. To develop a knowledge of the encapsulation of gamma ray sources.
4. To acquaint students with the geometric principles which apply to shadow formation.
5. To introduce problems caused by scattered radiation.

TEACHING AIDS:

1. Chalkboard or chart pad.
2. Figure references from *Industrial Radiography Manual*
   a) Shadow Formation (Fig. 9.9).
   b) Geometrical Unsharpness, the Penumbral Shadow (Fig. 9.10).
   c) Distortion of Shadows (Fig. 9.12).
   d) Shadow Formation Showing Enlargement of Image (Fig. 9.13).
   e) Sources of Scattered Radiation (Fig. 9.14).
   f) Backscatter from Floor, Walls, or Objects (Fig. 9.15).

REFERENCE:

Industrial Radiography Manual, Chapter 9.

LESSON:

Introductory Statement:

This chapter is designed to introduce the student to the basic principles which apply to the production and use of X and gamma radiation for radiography. Special emphasis should be given the geometric principles which must be considered in arranging radiography techniques. Students should be encouraged to study the several diagrams which are included as they are most helpful in understanding the formation of film images resulting from "radiation shadows" cast by the specimen and its discontinuities.

Teaching Outline:

I. Characteristics of X-radiation
   A. The energy of radiation is often expressed in electron volts.

Because this is such a small unit, kiloelectron (kev) and million electron volts (Mev) are the units most often used.

- B. As the wavelength of X-radiation becomes smaller, the energy of the radiation becomes greater. The higher energy radiation more easily penetrates dense materials.
- C. Radiation from an X-ray tube consists of two parts.
  - 1. The continuous X-ray spectra, which covers a wide band of wavelengths
    - a) This is the radiation of most use in industrial radiography.
    - b) A high tube voltage increases the intensity of continuous radiation.
  - 2. The characteristic X-ray spectra
    - a) X-radiation of a specific wave length
    - b) Energy of this spectrum is small compared to continuous spectrum
  - 3. A broad energy spectrum is sometimes not desirable since low energies are more readily scattered and absorbed. Filters are placed over tube windows to eliminate the lower energies.

II. Production of gamma rays—radioisotopes for gamma radiography are available from:

- A. Naturally occurring materials (Radium-226)
- B. Fission products (Cesium-137)
- C. Activation by neutron bombardment (Cobalt-60, Iridium-192, etc.)

III. Encapsulation of radioisotopes

- A. In gamma radiation the energy emitted from decaying nuclei is used.
  - 1. It is mandatory that the radioactive chemicals be contained so they will not come into contact with the human body.
  - 2. This containment is accomplished by sealing the materials in capsules.
  - 3. This process is called encapsulation.
- B. Encapsulation is a highly specialized process requiring the most careful:
  - 1. Design
  - 2. Fabrication
  - 3. Quality control
- C. Selection of materials and designs for capsules must consider:
  - 1. Resistance to corrosion from radioactive material and the outside environment
  - 2. Damage to capsule caused by emitted radiation
  - 3. Resistance to erosion, abrasion, and structural stresses
  - 4. Sealing techniques—fusion welding has been proven acceptable.
- D. Double encapsulation
  - 1. Some sources are now fabricated by sealing and testing in one capsule.
  - 2. This capsule is then sealed and tested in a second capsule.

- E. Leak testing sealed sources (refer to Laboratory Exercise 15.)
  - 1. All capsules must be tested for leaks after sealing.
  - 2. Exterior surfaces must be decontaminated to the degree that no more than 0.005 microcurie of removable contamination is present.
  - 3. All radiography gamma ray sources must be leak tested at intervals not exceeding 6 months (par. 13–9.3).

IV. Characteristics of gamma radiography sources

- A. Radioisotopes used for industrial radiography have discrete energies emitted (Fig. 3.8).
  - 1. Specimen thickness and atomic number determine the energy (wave length or Mev) required for penetration to make a radiograph.
  - 2. In selecting a radioisotope for a particular specimen, the desired characteristics are (Table 9.1):
    - a) Appropriate energy
    - b) High specific activity (provides sources having smaller dimensions)
    - c) Long half-life
- B. Metallic pellets are usually available for sources in the shape of cylinders. One or more pellets may be sealed in a capsule. (Cesium-137 sources are prepared by pressure pelletizing the radioactive chemical compounds Cs Cl.)

V. Geometric principles

- A. General considerations
  - 1. Shadow formation (Fig. 9.9)
    - a) Radiation beams behave much as light beams and form shadows
    - b) Relation of (1) film to object and (2) source to film distances determines size of shadow
  - 2. Sharpness of shadow depends on (Fig. 9.10):
    - a) Size of source
    - b) Ratio of the source to object distance and object to film distance
  - 3. Distortion of shadows may occur because (Fig. 9.12):
    - a) Plane of object and plane of the film may not be parallel
    - b) Object is not in contact with film
    - c) Radiation beam may not be directed perpendicular to the surface of film
- B. Enlargement (Fig. 9.13)
  - 1. With extremely small sources of radiation, the specimen may be placed some distance from the film.
  - 2. The result will be enlarged images.
- C. Geometric principles of shadow formation are the basis for the following recommendations:
  - 1. The radiation source should be as small as possible.
  - 2. The distance from the source to the film should be as great as possible. (Economy of exposure time must be considered in shop operations.)
  - 3. The film should be as close to the specimen as possible.

4. The center of the radiation beam should be perpendicular to the center of the film.
5. The plane of maximum interest on the specimen should be parallel to the film.

VI. Specimen

A. Radiography specimens vary from thin low density plastics to thick high density metallic materials.
B. Radiation interaction with and transmission through the section depend upon:
    1. Radiation energy
    2. Specimen atomic number
    3. Specimen thickness
    4. Density
C. Absorption coefficients indicate that:
    1. Radiation penetrates more easily as the energy increases.
    2. Radiation penetrates more easily as the material density, atomic number, and composition decrease.
D. Because of the above conditions, high energy radiation should be used to radiograph thick dense specimens and low energy radiation should be used to radiograph thin low density objects.

VII. Scattered radiation

A. Radiation interacts with any material (including air) and may be scattered. Compared to the primary beam, scatter has lower energy and may have more or less intensity.
B. Most scatter reaching the film is *forward scatter* (Fig. 9.14).
C. Hazy edges of images caused by scatter are called *undercut.*
D. *Back Scatter* is caused by radiation interacting with objects after passing the specimen (Fig. 9.15).

VII. Assign *Student Guide* Lesson 9.

Radiographic Film

TIME: One hour

OBJECTIVES:

1. To teach the students the characteristics of film used for industrial radiography.

2. To acquaint students with the procedures for determining the films best suited for particular operations.

3. To inform students of the requirements and precautions for each step of film processing.

4. To introduce students to the type of facilities needed for film processing.

TEACHING AIDS:

1. **Chalkboard or chart pad.**
2. **Figure references from *Industrial Radiography Manual***
   - a) **Film Characteristic Curve (Fig. 10.2)**
   - b) **Relative Film Speed (Fig. 10.3)**

REFERENCE:

***Industrial Radiography Manual*, Chapter 10.**

LESSON:

Introductory Statement:

Radiographic quality is dependent upon film emulsion characteristics. Speed and graininess must be considered in selecting techniques.

The processing of film is a vital step in industrial and other types of radiographic work. In order for the student to do a competent job, he must not only know the mechanical steps involved but must understand the theory as well. This chapter is designed to give the student the knowledge he needs for processing film. It should be stressed throughout the discussion that the standards for film processing are high and that all measurements of solutions, time, and temperature should be made carefully.

Teaching Outline:

I. **Introduction**
   - A. **Film is a prime essential for radiography work.**
   - B. **An industrial radiographic film is a thin, transparent, flexible, plastic base coated with an emulsion composed of gelatin containing microscopic crystals of silver bromide.**
   - C. **This chapter is concerned with the sensitometric characteristics of radiographic film.**

II. Radiographic contrast
  - A. Radiographic contrast is defined as a comparison of densities on developed film areas.
  - B. It depends on:
    1. X-ray kilovoltage or isotope gamma ray energy
    2. Screen type
    3. Film contrast characteristics
    4. Film density
    5. Scattered radiation
    6. Subject contrast

III. Subject contrast
  - A. Subject contrast is defined as the ratio of radiation intensities passing through two selected portions of a specimen.
  - B. Subject contrast varies according to the energy of the radiation and specimen atomic number and thickness.

IV. Film contrast, H & D Curve (Fig. 10.2)
  - A. Film is manufactured to give different film contrasts.
  - B. Film contrast is best described by the "characteristic" curve which relates film density to radiation exposure—the H & D curve.
  - C. Exposure (E) is defined as the product of the radiation intensity (I) reaching the film and the radiation exposure time (t). $E = I \times t$.
  - D. Characteristic curves are used in selecting radiographic technique as they show the relative speed and contrast of different types of film (Fig. 10.3).

V. Speed
  - A. Film speed is inversely proportional to the exposure required to attain a certain density.
    1. High speed (fast) film requires a low exposure
    2. Low speed (slow) film requires long exposure (Fig. 10.3).
  - B. Industrial operations are always concerned with time.

VI. Graininess
  - A. Film images are formed by multitudes of microscopic silver crystals, called grains.
  - B. Groups of grains produce an overall condition described as graininess.
    1. All films have graininess to some extent.
    2. Graininess determines the fineness of detail that can be perceived on film.

VII. In non-destructive testing the radiograph must interrelate film contrast, speed, and graininess to achieve an acceptable quality.

VIII. Radiographic screens
  - A. Radiographic screens are used to intensify the photographic action of radiation on the film.
  - B. The two most used types are:
    1. Lead foil screens, which are commonly used on both sides of the films to improve quality

        - a) Such screens should be selected and handled with extreme care.
        - b) They should be cleaned carefully and should not contain irregularities or abrasions.
    2. Fluorescent screens are used with film which has a high sensitivity to blue light.
        - a) Seldom used in industrial radiography
        - b) Should not be touched or cleaned without consulting manufacturer's instructions

IX. Film processing (Use chemicals recommended by film manufacturers.)

- A. The chemical processing of film is an important and exacting task.
- B. Several general precautions apply to film processing:
    1. Specified limits should be observed for all chemical concentrations, solution temperatures, and processing times.
    2. Scrupulous cleanliness is mandatory.
    3. Equipment should be made from materials which do not corrode in contact with processing chemicals.
    4. Suitable darkrooms and safe lights are required since emulsions are sensitive to light.
- C. Developing involves:
    1. Careful adherence to time and temperature recommendations, 5–8 minutes at 68°F
    2. Agitation of film
    3. Timely replenishment and/or replacement of developer solution
- D. Stop bath involves:
    1. Allowing developer to drain from the film
    2. Immersion in stop bath for 30–60 seconds with moderate agitation
- E. Fixation involves:
    1. Allowing proper time—8 to 15 minutes at 68°F
    2. Vigorous agitation when first placed in solution
    3. Replenishment and/or replacement of solution at intervals
- F. Washing involves:
    1. Use of adequate size tanks
    2. Running water
    3. Fresh uncontaminated water
- G. Drying involves:
    1. Immersion of washed film in wetting agent when possible
    2. Circulation of dry, warm air over film
    3. Use of filters for air

X. Film processing facilities

- A. The location, design, and construction of film processing facilities is important. Volume and character of work determines specifications.
- B. The darkroom should have:
    1. Adequate safe lights
    2. Corrosion resistant walls and floors
    3. Properly designed darkroom entrances

C. Equipment which meets all standards of size, safety, and corrosion resistance
D. Film dryers with adequate filters and fast heating controlled to prevent melting the emulsion
E. Automatic film processing equipment

XII. Assign *Student Guide* Lesson 10.

Radiography Techniques

TIME: Two hours

OBJECTIVES:

1. To inform students of practical guides for X and gamma radiography exposure arrangements.
2. To teach students methods for calculating exposure time.
3. To present principles for selecting practical radiography techniques.
4. To study causes and corrections of unsatisfactory radiographs.

TEACHING AID:

Chalkboard

REFERENCE:

Industrial Radiography Manual, Chapter 11.

LESSON:

Introductory Statement:

The material preceding this lesson has been primarily concerned with principles. This lesson is to present techniques which have been tried and proved to be practical for industrial radiography. Successful radiographers must know and use the rules and guidelines in this lesson. Shop and laboratory experience will be necessary for the student to gain ability and confidence to radiograph the many different industrial specimens.

Teaching Outline:

I. Exposure calculations, defining and controlling variables.
   A. Chemicals and film processing.
      1. Concentrations, replenishing.
      2. Time-temperature.
      3. Washing and drying.
      4. Cleanliness.
   B. Films.
      1. Speed, graininess, contrast.
      2. Film factor, "F".
   C. Screens.
      1. Metallic foil.
      2. Fluorescent.
   D. Geometry (minimum criteria)
      1. SFD = 8 x specimen thickness (Fig. 11.1)
      2. SFD = diagonal length of radiograph (Fig. 11.2)

- E. Specimen
    - 1. Steel equivalent thickness (S.E.T.) (Acceptable for gamma ray energies within a limited range)
    - 2. Radiation penetration
    - 3. Absorption factor "A"
- F. Source emissivity
    - 1. X-ray "ma"
    - 2. Gamma ray sources "S"
- G. Exposure calculations
    - 1. Gamma ray (Fig. 11.3)

$$T = \frac{FAD^2}{S}$$

    - 2. X-ray (Fig. 11.5)
- H. Control of scatter
    - 1. Filters
    - 2. Screens
    - 3. Masks, diaphragms and blocking

II. Exposure arrangements

- A. Location of source and film relative to specimen
- B. General questions
    - 1. Which arrangement will give the best radiographic image of the specimen area that is likely to contain manufacturing discontinuities?
    - 2. Which arrangement will give the best radiographic image of the specimen area that is likely to fail under imposed operating stresses?
    - 3. Which arrangement will allow the shortest exposure time without unnecessarily sacrificing radiographic quality?
    - 4. Will the subject contrast require (a) single film, (b) double film, or (c) multiple exposure techniques?
    - 5. Can beam or panoramic radiation be more appropriate?
- C. Emitted beam shapes
    - 1. X and gamma ray
    - 2. Angular
    - 3. 360° limited angle beam
    - 4. 360° spherical beam
- D. Source, film, specimen arrangements
    - 1. Flat specimens having uniform thickness
    - 2. Pipe
        - a) Small diameter, 1½ inches or less
        - b) Large diameter
            - (1) Multiple exposures
            - (2) Panoramic exposures
    - 3. Pressure vessels
    - 4. Spheres and hemispheres
    - 5. Panoramic exposure for many specimens
    - 6. Techniques for specimens having large subject contrast

III. Unsatisfactory radiographs, causes and corrections

- A. High density
    - 1. Overexposure

        2. Overdevelopment
        3. Scatter
    B. Low density
        1. Underexposure
        2. Underdevelopment
            a) Time
            b) Depleted developer
            c) Temperature too low
    C. High radiographic contrast
        1. Low energy
        2. High subject contrast
        3. High film contrast
    D. Low radiographic contrast
        1. High energy
        2. Low subject contrast
        3. Low film contrast
        4. Underdevelopment
    E. Poor definition
        1. Geometry
        2. Poor screen to film contrast
        3. Graininess
        4. Fluorescent screens
    F. Fog
        1. Scatter
        2. Light leaks
        3. Chemical fog from overdevelopment
        4. Excessive film exposure to
            a) Stray radiation
            b) Heat
            c) Humidity
            d) Vapors and gases
        5. Film age
    G. Streaks
        1. Contaminated hangers
        2. Agitation
        3. Water spots during drying
    H. Yellow stain
        1. Old, oxidized developer
        2. Omission of stop bath
        3. Improper fixation
    I. White scum
        1. Improperly mixed fixer
        2. Developer in fixer
    J. Mechanical damage to emulsion
        1. Scratches
        2. Pressure marks
        3. Frilling and sloughing
    K. Static electricity

IV. Assign *Student Guide* Lesson 11.

Interpretation Of Radiographs

TIME: Two hours

OBJECTIVES:

1. To inform the student that the radiography process is not complete until analysis and interpretation of the results have been made.
2. To teach the concepts of interpreting test results in their relationship to design and performance of materials and structures.
3. To acquaint the student with the discontinuities likely to be found in welds and castings.
4. To present the general ideas relating to "quality levels" and "acceptance and comparison standards."
5. To study specifications and reference radiographs.
6. To review radiographic codes as they are used in industry.

TEACHING AIDS:

1. Chalk board or chart pad.
2. Figure references from *Industrial Radiography Manual*
   a) Penetrameters (Fig. 12.1)
   b) A.S.M.E. Porosity Charts (Fig. 12.2)
   c) A.P.I. Standards for Field Welding of Pipelines (Fig. 12.3)
3. ASTM reference code card for steel welds.
4. Sample Radiographs (to be prepared by the instructor for comparison of specimens to radiographs)

REFERENCES:

1. *Industrial Radiography Manual*, Chapter 12.
2. Radiographic reference codes and charts prepared by:
   a) American Society of Mechanical Engineers.
   b) American Society for Testing and Materials.
   c) American Petroleum Institute.
   d) American Welding Society.
   e) U. S. Army Ordnance Department.
   f) U. S. Air Force.
   g) U. S. Navy.

LESSON:

Introductory Statement:

The aim of this lesson is to teach the student that the capable radiographer must be able to interpret images of discontinuities observable on a radiograph. Engineering designs and specifications should be prepared to include considerations of material testing. The "Non-Destructive Testing" (radiography, in this program) of industrial materials and structures has the objective to prove that the items have been fabricated in such a manner that contained discontinuities do not exceed certain conditions that might impair the usefulness or serviceability of the product.

Limited classroom time precludes thorough study and practice of radiograph interpretation. The student must be introduced to the published and accepted code. Reference and comparison standards and porosity charts provide suitable guides for radiograph interpretation.

General discussions of weld and casting discontinuities should be related to images on radiographs and charts.

Teaching Outline:

I. Basic concepts of interpretation
  A. General considerations
    1. Engineering design specifications
    2. Product serviceability
  B. Acceptable quality levels
  C. Quality levels and manufacturing
  D. Specifications and reference standards—reference radiographs

II. Metal discontinuities (defects)—general classifications
  A. Cracks and breaks
  B. Holes and porosity
  C. Lack of fusion
  D. Inclusions
  E. Surface irregularities

III. Radiographic Sensitivity
  A. Percentage sensitivity
  B. Penetrameters (Fig. 12.1)
  C. Reference radiographs and charts (Figs. 12.2 and 12.3)

IV. ASME codes (an example for discussion in this limited program) It is not intended to minimize the importance of other codes.

V. ASTM Radiographic reference materials

VI. Radiographs of welds
  A. Gas holes and porosity
  B. Weld slag inclusions
  C. Cracks or breaks
  D. Lack of penetration
  E. Lack of fusion
  F. Inclusions
  G. External discontinuities

VII. Radiographs of castings
  A. Gas holes
  B. Porosity
  C. Shrinkage cavities
  D. Inclusions
  E. Misruns
  F. Cold shuts

G. Cracks
H. Core shift
I. Hot tears
J. Segregation
K. Microshrinkage
L. Surface irregularities

VIII. Assign *Student Guide* Lesson 12.

Lesson 13

Government Licensing, Health, and Transportation Regulations for Radiography

TIME: Two hours

OBJECTIVES:

1. To inform radiography students of the requirements and conditions of licenses for use of byproduct materials.
2. To inform radiography students of the general considerations necessary for protection against radiation hazards.
3. To acquaint radiography students with the precautionary procedures and records, reports and notification procedures required of persons holding licenses to use byproduct materials.
4. To inform students of the qualifications and skills which a radiographer and a radiographer's assistant must possess and to acquaint students with the various types of training programs for radiographers.
5. To inform students of the various government regulatory bodies which govern transportation of radioactive materials and to provide the student with a general knowledge of ICC, CAR, U. S. Postal Service, and U. S. Coast Guard regulations for ordinary shipments of radioactive materials.

TEACHING AIDS:

1. Chalkboard or chart pad.
2. From *Industrial Radiography Manual*
   a) Application for Byproduct Material License—Use of Sealed Sources in Radiography (Form AEC-313R) (Fig. 13.1)
   b) Occupational External Radiation Exposure History (Form AEC-4) (Fig. 13.2)
   c) Current Occupational External Radiation Exposure (Form AEC-5) (Fig. 13.3)
   d) Radiation Symbol and Signs (Figs. 13.4, 13.5, 13.6, and 13.7). (This chart should be prepared with the proper colors.) (It is desirable to give copies of the signs to students. These are available as (1) GPO 0–496032, and GPO 961771.)
   e) AEC Regional Office Locations (Form AEC-3) (Fig. 13.8)
   f) Interstate Commerce Commission Red Label and Blue Label for Class D Poisons (Figs. 13.9 and 13.10)

REFERENCES:

1. *Industrial Radiography Manual,* Chapter 13.

2. AEC Licensing Guide for INDUSTRIAL RADIOGRAPHY.
3. Code of Federal Regulations: Title 10, Parts 20, 30, and 31; Title 49, Parts 71–77; Title 14, Part 49; Title 46, Part 146.
4. U. S. Postal Manual.

LESSON:

Introductory Statement:

This lesson is designed to acquaint the student in a general way with the regulations which apply to industrial radiography licenses, to radiation safety in such operations, and to the rules which govern the transportation of radioactive materials. It should be stressed that the Code of Federal Regulations and other pertinent Federal documents plus the regulations of the "Agreement States" and other "bodies" are the final authority on requirements and standards for industrial radiographic work. The *Industrial Radiography Manual* is not official, although it is based on the appropriate regulations.

The importance of a thorough knowledge of government regulations for radiography students is obvious. Radiographers are called upon to aid in the preparation of applications for byproduct licenses and, under such licenses, have major responsibility for training programs and for establishing and maintaining radiation protection standards in accordance with established procedures and practices.

Teaching Outline:

I. The authority for AEC regulations
   A. The AEC is responsible for the atomic energy program. The Commission establishes regulations and licenses uses of selected nuclear materials pursuant to the Atomic Energy Act of 1954.
   B. In actual practice, the AEC sets standards for its operations and for licenses on the basis of its operating and research experiences and on the recommendation of the Federal Radiation Council.
   C. Regulations and safety rules are drawn to limit personnel radiation exposure below danger levels and to afford acceptable protection for the general public.

II. Licensing and policing authority of States and other "bodies"
   A. The Atomic Energy Act was amended in 1959 so that the AEC could enter into an agreement with a State which permitted the State to assume certain regulatory authority.
      1. This authority is specifically limited to byproduct material and source and special nuclear material.
      2. States accepting these responsibilities are called "Agreement States."
      3. "Agreement States" regulations must be compatible with AEC regulations and all such States must have reciprocal agreements with one another as well as competent personnel to operate a regulatory program.
   B. Other "bodies," such as port authorities, counties, cities, etc., may also have regulatory power over radiation sources.

III. Requirements for a specific license to use byproduct materials for radiography

- A. Specific licenses are required of all persons who "manufacture, produce, transfer, receive, acquire, own, possess, use, import, or export" byproduct material.
- B. The first step in the application for a specific license is the filing of Form AEC-313R (Figure 13.1).
- C. The general requirements which must be met for issuance of a specific license are:
  - 1. The application must be for an authorized purpose.
  - 2. The applicant's proposed equipment and facilities must be adequate to protect health and minimize danger to life and property.
  - 3. The applicant must be thoroughly qualified by training and experience to use the byproduct material for the purpose requested.
  - 4. The applicant must show that he has an adequate program for training radiographers and radiographers' assistants.
- D. All specific licenses are granted on the condition that detailed records showing the receipt, transfer, export and disposal of byproduct materials are kept and made available for periodic inspection.

IV. Conditions and control and licenses

- A. Violations of licensing requirements are punishable by fine and imprisonment.
- B. Regulations do not allow transfer of a license to another person except by written permission from the appropriate authority.
- C. Each specific license includes an expiration date and all work must be suspended at this time unless a renewal is granted on the basis of an application.
  - 1. Such applications must be filed at least 30 days before expiration of the old license.
  - 2. The old license will remain in effect so long as the renewal application is pending.
- D. Licenses may be revoked or suspended for two primary reasons:
  - 1. The making of false statements in connection with the application
  - 2. The discovery of conditions in violation of the license
- E. A licensee may have his license amended to include new types of operations by submitting an application for amendment.

V. General considerations for protection against radiation

- A. Safety standards are designed to prevent individual workers from receiving excessive radiation exposure and to safeguard the general public.
- B. It is necessary that the radiographer be acquainted with the precise meaning of the words used in the regulations, if he is to practice safety in accordance with accepted standards. Definitions should be reviewed at this point. (Students should be encouraged to use the Glossary in Appendix A.)

C. In radiography operations it is impractical or impossible to prevent some exposure of individuals to radiation.
  1. Equipment designs and controlled procedures permit the radiographer to work without receiving excessive radiation doses.
  2. Exposure limits in restricted areas are:
     a) Whole body, head and trunk, active bloodforming organs, lens of eyes, or gonads .... 1¾ rem
     b) Hands and forearms, feet and ankles .....18¾ rem
     c) Skin of whole body .... 7½ rem
  3. Doses in excess of the limits prescribed are allowed providing they do not exceed 3 rems per calendar quarter and do not exceed 5(N–18).
  4. "Tolerance dose" for routine work must not exceed 100 mr/week.

D. Radiation levels in unrestricted areas are permitted so long as they will not cause any individual to receive accumulated dosage to the whole body in excess of:
  1. 0.5 rem in one calendar year
  2. 2 millirem in one hour
  3. 100 millirem in seven consecutive days

E. Persons under 18 years of age are normally not allowed to be involved in radiography operations because of their greater susceptibility to radiation damage.

F. Radiation signs and symbols must be used in certain places and situations to be covered later. The prescribed symbol and signs are shown in the *Manual* (Figs. 13.4–13.7).

G. Other general conditions for protection against radiation include:
  1. The observance of specified limits on levels of radiation for radiographic exposure devices and storage containers.
  2. The use of properly calibrated and operable survey meters for surveys of radiation fields.
  3. The proper tagging of sealed sources not fastened to or contained in a radiographic exposure device.

VI. Precautionary Procedures and Records Required of Licensees.

A. Certain precautionary procedures must be outlined in an application for license. To be acceptable they must include:
  1. Radiation surveys to evaluate the hazards incident to all radiographic operations. Survey records must be kept on file for review.
  2. Storage of licensed material in safe places.
  3. Personnel monitoring so that exposure limits can be carefully measured and controlled (Figs. 13.2 and 13.3)
  4. Use of caution signs, labels and signals as prescribed (Figs. 13.4–13.7)
  5. Careful and complete instruction of personnel on all regulations and procedures.
  6. Proper waste disposal.

B. Full reports and records of all radiographic operations must be maintained on the proper forms.

C. The proper authorities must be notified immediately of incidents involving severe overexposure, release of excessive radioactive materials, property damage, loss of facility use, and theft (Fig. 13.8)

VII. Qualifications and training of radiography personnel

   A. The two types of radiography personnel are:
      1. Radiographer—who bears direct responsibility to the licensee's management for compliance with regulations. He must be in direct attendance at the site of use of radioactive materials.
      2. Radiographer's Assistant—who manipulates equipment and material related to radiography under the direct supervision of a radiographer.
   B. Radiographers and their assistants must meet certain minimum training requirements and each applicant for a license must have an adequate program for training such personnel.
      1. Training programs must include
         a) Initial training
         b) Periodic training
         c) On-the-job training
         d) Methods for determining qualifications of personnel
      2. Arrangements may be made for the initial training to be done by qualified consultants.

VIII. Organizational structure of radiography programs

   A. Regulations require that each applicant for a specific license submit a description of the overall organizational structure of his radiography program.
   B. It is necessary to show specifically how authority is established and responsibility delegated for operation of the program.

IX. Other requirements for industrial radiography operations

   A. It is also required that applicants for licenses establish a satisfactory internal inspection system to assure that applicable regulations are followed.
   B. All applicants for licenses must, in addition, prepare detailed operating and emergency procedures as part of their applications. These procedures must be tailored to their specific operations and include:
      1. Specific instructions on the handling of exposure devices and related equipment
      2. Specific instructions on the operation, use and limitations of survey equipment
      3. Methods for controlling access to radiographic areas
      4. Methods and occasions for locking and securing exposure devices and sealed sources
      5. Personnel monitoring devices required
      6. Instructions on transportation
      7. Instructions on records to be kept
      8. Instructions on what to do in case of malfunction
   C. All sealed sources must be tested at intervals not to exceed six months to detect leaks. (Refer to Laboratory Exercise 15.)

D. When accidents which threaten public health and safety occur, emergency radiological assistance may be obtained from the Interagency Committee on Radiological Assistance. Requests should be sent through the AEC-DOD Joint Nuclear Coordinating Committee.

X. Transportation of Radioactive Materials.

A. All transportation of radioactive materials moving in interstate commerce by rail, water or public highway (except U. S. mail) is regulated by the Interstate Commerce Commission. The Civil Aeronautics Board controls air transportation, and water transportation is under the jurisdiction of the U. S. Coast Guard. Interstate transportation is governed by local regulations.

B. ICC regulations are designed to minimize dangers to life and property incident to the transportation of radioactive materials. To this end:

1. ICC classifies radioactive materials as Class D poisons and subdivides these materials into three groups for regulation purposes.
   a) Group I—including materials that emit gamma rays only or both gamma and electrically charged corpuscular rays—is the group of principal concern to radiographers.
   b) Group II—includes materials that emit neutrons and either or both types of radiation characteristic of Group I.
   c) Group III—includes radioactive materials that emit electrically charged corpuscular rays only.
2. The ICC exempts packages which pass the following tests from its regulations.
   a) Packages which are rugged enough to withstand ordinary conditions of transportation without leakage of radioactive material.
   b) Packages in which the total activity of the contents does not exceed 0.1 millicurie of radium or polonium; that amount of strontium-89, strontium-90, or barium-140 which disintegrates at a rate of more than 5 million atoms per second; and not more than that amount of any other radioactive substance which disintegrates at a rate of more than 50 million atoms per second.
3. Two criteria are accepted by the ICC for adequate packing and shielding.
   a) Under normal conditions the degree of fogging of undeveloped film must not exceed that produced by 11.5 milliroentgens in 24 hours of penetrating gamma rays of radium filtered by one-half inch of lead.
   b) There must be no significant radioactive surface contamination on any part of the container.
4. ICC labeling regulations are as follows:
   a) All Group I and Group II packages must have a

2

Class D poison, Group I and Group II label (red label) attached (Fig. 13.9)

b) Packages of radioactive materials whose surface radiation is less than 10 mr/24 hr. (0.4 mr/hr.) but whose radiation is too great for exemption, require a Class D Poison, Group III label (blue label) (Fig. 13.10)

5. Diamond shaped placards measuring 10¾ inches on each side and bearing the words DANGEROUS—RADIOACTIVE MATERIALS must be applied to railway cars and motor vehicles transporting any quantity of radioactive materials. Motor vehicles and trailers carrying radioactive materials must be marked and placarded on each side and rear in letters not less than three inches high on a contrasting background with the words: DANGEROUS—RADIOACTIVE MATERIALS.
6. Shippers of radioactive materials must describe the articles on shipping orders, bills of lading and other shipping papers, and show thereon the color and kind of label applied to the package. Both red and blue label packages must contain a certification on the label that the package contents are properly described, packed, and marked.
7. Accidents and violations of ICC regulations must be reported to the Bureau of Explosives as quickly as possible.

C. Civil Air Regulations governing the transportation of radioactive materials are essentially the same as ICC regulations, with one major exception. Standards for storage aboard aircraft, because of distance and time factors, differ substantially from standards applying to ground transportation.

D. Postal regulations governing the mailing of radioactive materials state that any label required by federal law or federal agencies must be placed on packages and the nature of the contents must be plainly shown along with name and address of mailer. In addition, the package must incorporate a "safe" design and must not emit from its exterior any significant alpha, beta or neutron radiations.

E. U.S. Coast Guard regulations governing water transportation of radioactive materials are the same as ICC regulations for packaging and labeling requirements. However, the acceptability, handling and storage aboard ship are the responsibility of the U.S. Coast Guard.

XI. Assign *Student Guide* Lesson 13.

Appendix

Suggested Typical Examination

Industrial Radiography Course Examination

Name .... Date ....

Define these terms as related to AEC regulations:

1. Radiographer
2. Survey
3. Leak test
4. Radiographer's assistant
5. Personnel monitoring
6. Banking concept
7. Radiation area
8. Occupational dose
9. Sealed source
10. Survey
11. Person
12. Utilization log

Briefly answer the following:

13. Describe how a calibration curve is useful to a radiographer.
14. State some characteristics of a gamma ray.
15. What is the difference between *dose* and *dose-rate?*
16. Relative to personnel dosage, what is the effect of exposure time?
17. Relative to personnel dosage, what is the effect of distance?
18. Relative to personnel dosage, what is the effect of shielding?
19. What is "reduction factor"?
20. List the most important characteristics of a survey meter used by radiographers.
21. What is scattered radiation?
22. Describe the three signs which are to be used by radiographers. State the conditions under which each should be used.
23. What are the allowable radiation intensities around radiography exposure devices?
24. List the records which are required to be maintained by radiography installations.
25. How may a radiographer dispose of decayed sources?
26. For what two reasons may an AEC license be revoked?
27. Why should you be careful when selecting a Geiger counter for surveying around radiographic operations?
28. When should a radiographer make surveys?
29. Outline the minimum acceptable operating procedures.

30. What markings are required on the outside of vehicles used for transporting radioisotopes?

Work these problems. Show all calculations on the test paper. If more space is needed use the back of the sheets.

31. The emission rate from a source is 5 roentgens per hour at 8 feet from the source. Determine the emissivity at 1 foot from the source.
32. A 5-curie source of Co-60 is to be used 10 feet from a group of men. Determine the radiation intensity the men will receive when the source is exposed.
33. In problem 32, determine the length of time the men can remain in the radiation field without receiving more than 100 mrem.
34. A 30 curie source of Ir-192 is to be used 8 feet from a lathe operator. How thick must a concrete wall be built to prevent him from receiving more than 2 mr/hr? (Use half value layers.)
35. A Cs-137 source of radiation has an intensity of 10,000 mr/hr at a distance of 15 feet from the source. How much lead shielding will be required to reduce the dose-rate to 2.5 mr/hr? (Use reduction factor.)
36. It is desired to calibrate an Ir-192 source. A dosimeter is charged to 3 mr and exposed for 6 minutes at 10 feet from the source. After the exposure the source of radiation had caused the dosimeter to read 157 mr. The calibration was made on January 1, 1965 by Mr. J. Ray de Ographer at the Cajun Exposure Emporium, Inc. The source was marked with serial number 147A5 by the E. N. Capsulator Corporation.

    Determine the source activity and plot a decay curve for the source. (Be sure to properly place the proper information on the curve sheet.)
37. A survey meter has ranges 0-20, 0-200, and 0-2,000 mr/hr. It is desired to calibrate this source on May 1, 1965. Use the source described in problem 36.

    Describe the calibration procedure, limits of accuracy, and all calculations for assuring this instrument is working properly. What would you do if it were determined the instrument is not working properly?

☆ U.S. GOVERNMENT PRINTING OFFICE: 1968 O—264-302

OE-01
SE

UNITED STATES
GOVERNMENT PRINTING OFFICE
DIVISION OF PUBLIC DOCUMENTS
WASHINGTON, D.C. 20402

OFFICIAL BUSINESS

POSTAGE AND FEES PAID
U.S. GOVERNMENT PRINTING OFFICE

U.S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE

Office of Education

● U.S. ATOMIC ENERGY COMMISSION

OE-84034